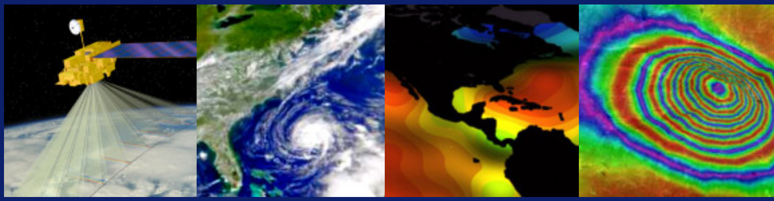
Exploration Systems Autonomy

2002 Research Update

Focus on Earth Science

Investigator Update

Award-Winning Technologists



JET PROPULSION LABORATORY

We provide computing and autonomy technologies to enable the coming generations of highly autonomous and scientifically productive robotic space missions. We provide software systems, new algorithms, advanced computational approaches, and new discoveries that create novel capabilities and increase the scientific return of JPL and NASA's robotic missions.

The span of our research and development activities enables advances in Earth system science as well as deep space exploration. In this year's report we highlight our Earth-focused research, performed in support of the first article of NASA's mission statement: "to understand and protect our home planet."

Dr. Anna Tavormina

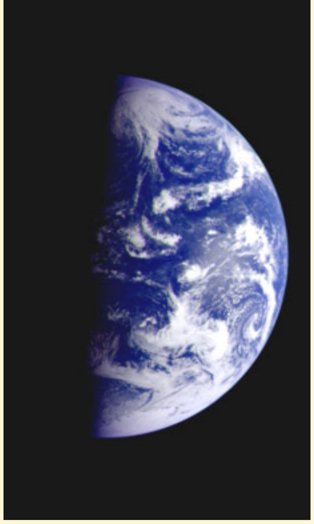
SECTION MANAGER

Dr. Thomas Yunck

DEPUTY SECTION MANAGER

Contents

Earth Intelligence Report	2
Earth and Space Science Computing with the Information Power Grid	6
Improving Earth Science Return Through Autonomous Scene Selection	8
A New Dimension in Earth Imaging: MapUS and Beyond	10
Our Ocean: A Web Portal to Serve Near-Real-Time Coastal Ocean Data Products	12
Scientists Finding the Right Data: Data Mining of Massive Time-Series and Image Datasets	14
GeoFEST: A Tool for Modeling Earthquakes	16
Quantum Sensors: Enabling a New Sensitivity for Earth Science	18
Inverse Problem Approach to Information Processing	20
Applying Advanced Image Processing Techniques to Enhance Underground Radar Images	22
Award-Winning Technologists 2002	23



NASA's Earth Science Enterprise has set for itself the imposing goal of elucidating our dynamic planet in full: as a tightly woven, almost living web of physical processes and feedbacks. This pursuit, known as Earth System Science, emerged in the 1980s with the announcement of the Earth Observing System, a varied suite of remote-sensing satellites fashioned to gather the breadth of needed data. Earth System Science will continue to unfold over decades, with one overriding purpose: to discern the environmental outcomes of human and natural events and thus guide our stewardship of (as yet) our only home.

Earth Intelligence Report

The theme of this undertaking is "From Sensors to Knowledge." On NASA's ambitious timeline, 2002–03 marks a transition from "characterizing" to "understanding" the Earth system. A generation of sensors is now in place. The flagship Terra and Aqua platforms are aloft, with Aura soon to follow. GRACE and other focused probes are in service. The challenge is no longer just to collect global data, but something more profound: to distill the mounting petabytes into a body of knowledge by which we can one day foresee and perhaps influence Earth's contingent changes.

Information Science to the Fore

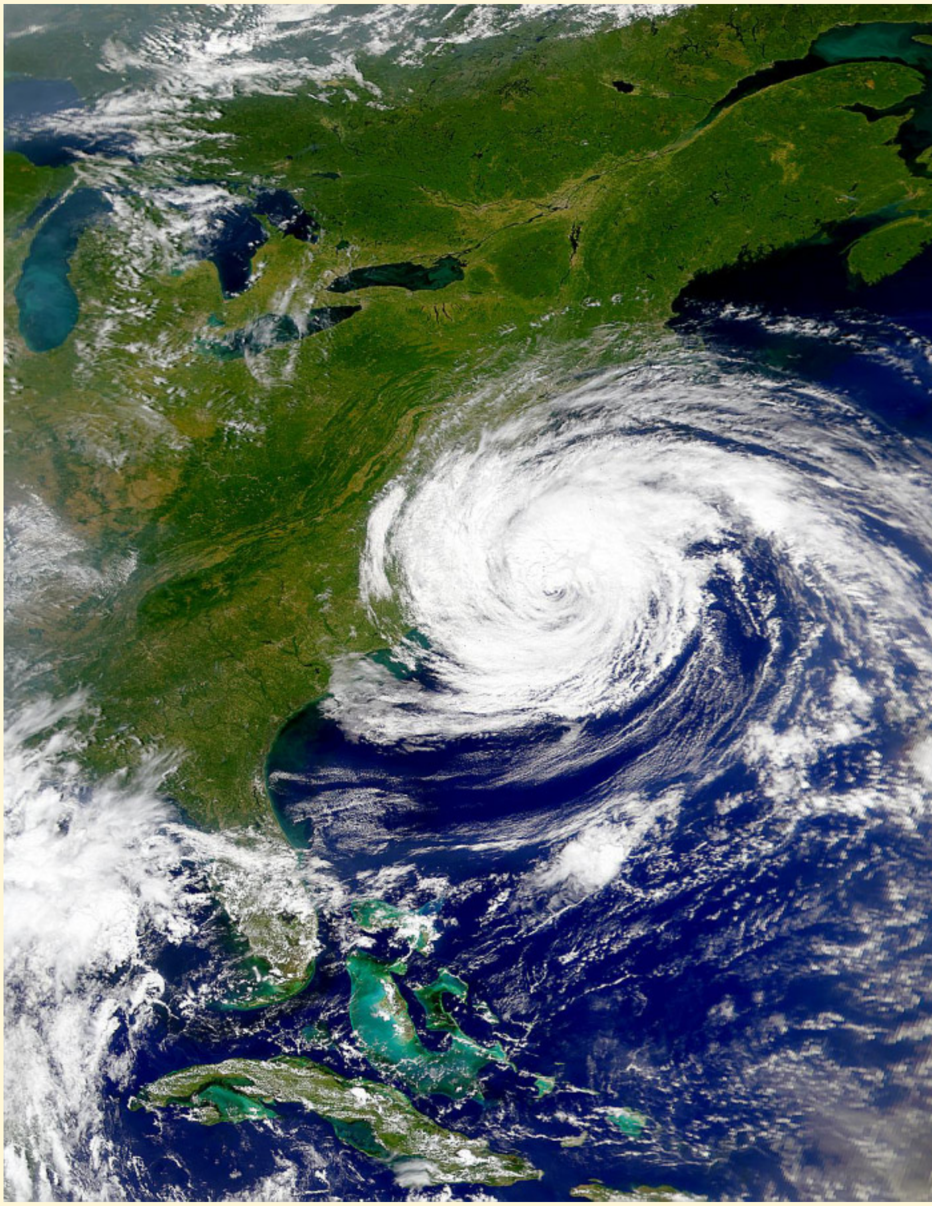
The spotlight is thus shifting from the tools of collection to the tools of reduction. We require methods of rendering this vast harvest into stores of knowledge that can lead to reliable environmental prediction, and possibly improvement. As the information revolution quickens, these technologies are taking a central part in the drive to illuminate and preserve our hospitable world.

The Exploration Systems Autonomy Section, home within JPL for frontier information technology, in partnership with scientists here and around the world, is helping to create these solutions. In this report we highlight current activities in Earth-focused research and announce a new office to help shape our Earth programs.

At present this work embraces such disciplines as data fusion and mining, machine learning and automated discovery, ultracomputing and quantum technologies, sensor webs and system autonomy, on-the-fly animation of massive datasets, and precision scientific modeling. The diversity of Earth applications is sampled in this report.

New Roles, New Sensors

The scope of our Earth initiatives goes beyond Earth science. The first article of NASA's stated mission is "to understand and protect our



Advanced information technologies are helping to illuminate questions of global climate change, weather prediction, and environmental science. A key resource is GENESIS, the Global ENvironmental and Earth Science Information System *(http://genesis.jpl.nasa.gov)*.

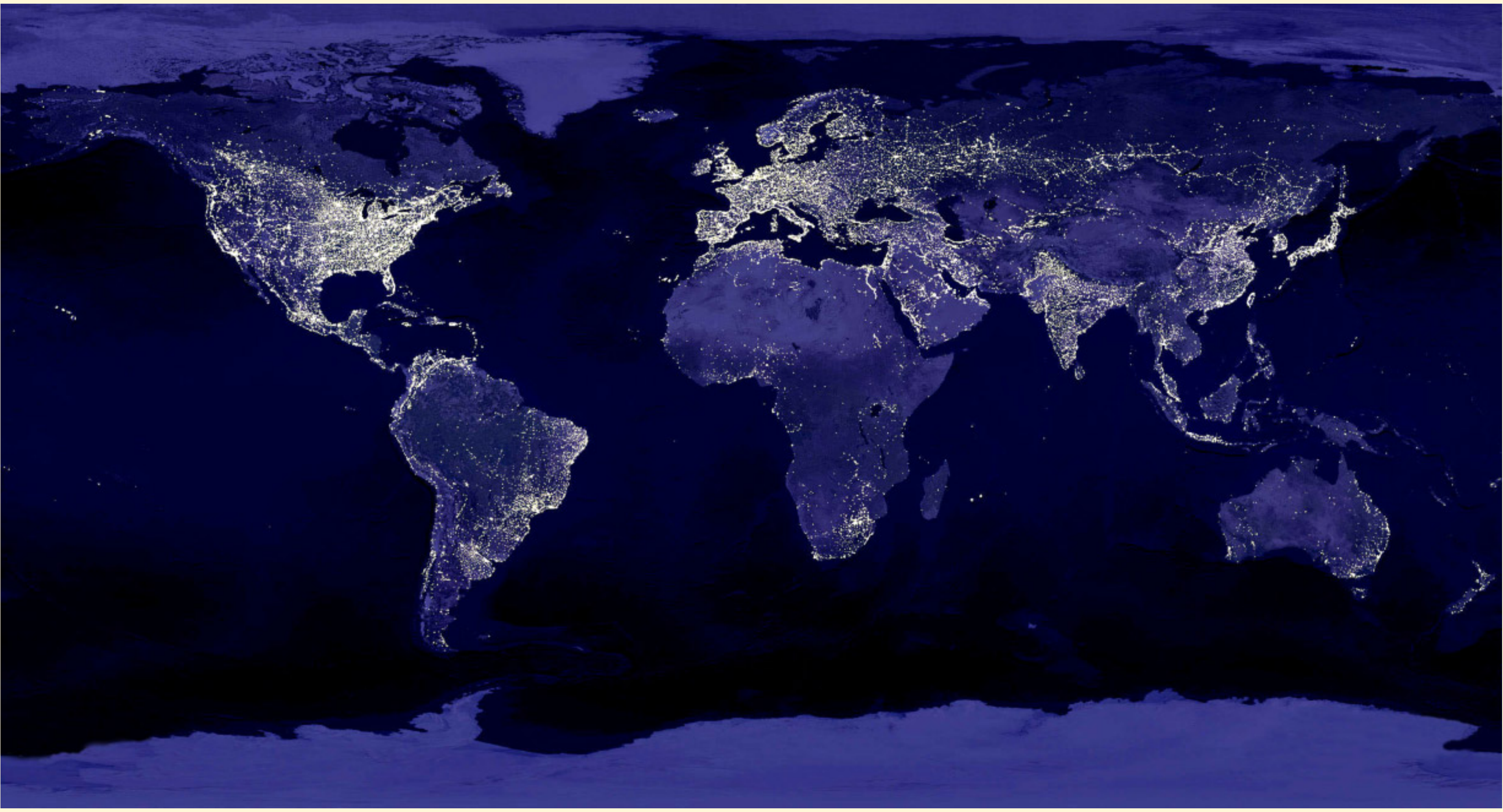
home planet." Recent events have brought issues of public security to the fore. Many of the techniques devised to explore Earth can apply directly in that cause. We are working to adapt Earth science technologies to better secure our homelands — nation and planet alike.

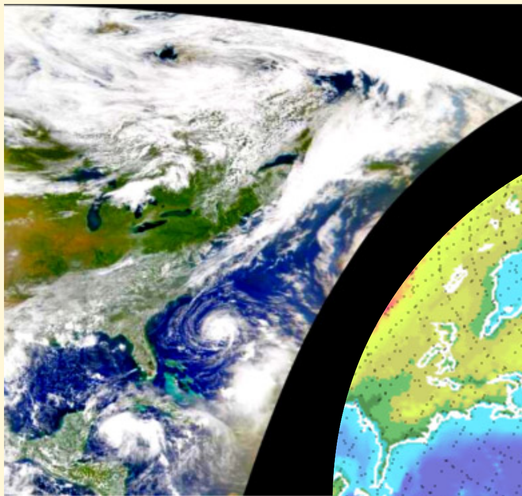
Present sensors cannot answer all questions critical to predicting global change. New technologies will soon be needed. In many areas of detection, the cutting edge lies in the extraordinary sensitivities — and bizarre properties — of quantum systems, including quantum dots and gyros, entangled photon pairs, and quantum interferometers. Our Quantum and Ultra Computing Technologies Groups continue to push the frontiers with novel concepts for quantum magnetometers, gravity gradiometers, underground imagers, and chemical sensors — concepts that will surface in a new wave of revolutionary detectors.

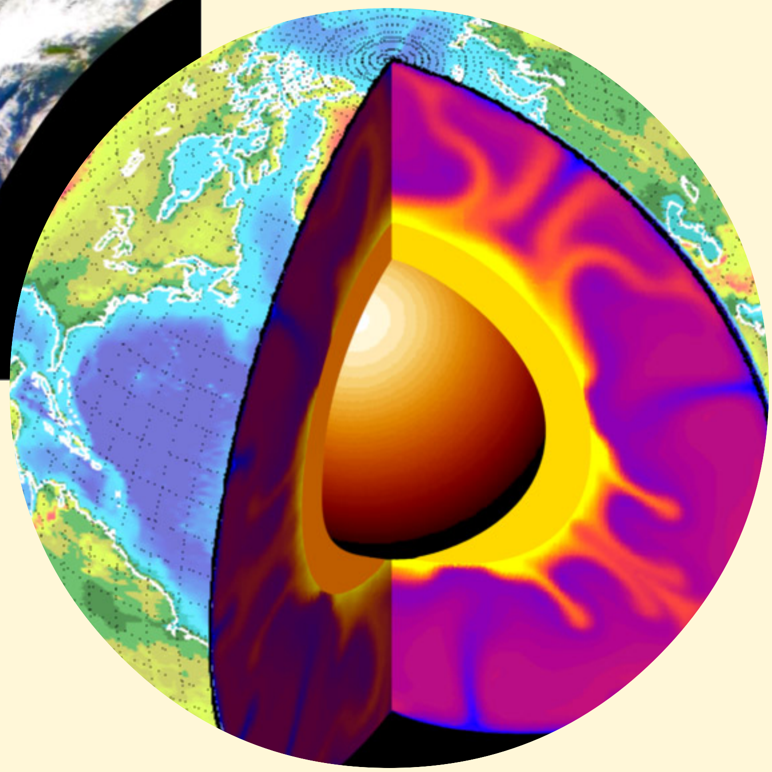
Intelligence on Earth

A key aim in this work is to apply our skills to understanding the Earth in ways that can help guide our national environmental policies. To that end, the Section has inaugurated an Earth System Information Technology Office, with Dr. David Curkendall as manager.

This nighttime mosaic of the Earth from space shows the expanding concentrations of civilization around the globe, a source of increasing stress to our hospitable environment.







Application of automated machine learning, data mining, and data understanding techniques to seismic and geodetic observatories will advance our knowledge of earthquake processes and of the dynamics of the Earth's crustal plates and deep interior.

Our vision for the office is simple: *Gather and distill information on our home planet to fathom its workings and enhance our lives, our security, and our care of Earth's treasures.*

One might say we are seeking to increase the sum of intelligence on Earth: intelligence as information, as understanding, as wisdom. It has been observed that Earth exhibits its own canny intelligence, commanding myriad controls and feedbacks to restore a state of benign comfort through every manner of disturbance — a cunning that has nurtured abundant life in a line unbroken for nearly four billion years.

The great environmental question today is whether this happy property can survive the intrusions of human enterprise; or, more to the point, how we can govern our actions to ensure that it will. It is a question that must be answered soon. It is the first priority of NASA's Earth science program. In the global quest for solutions, JPL's Exploration Systems Autonomy Section seeks to play a vital, perhaps pivotal role.

Contact

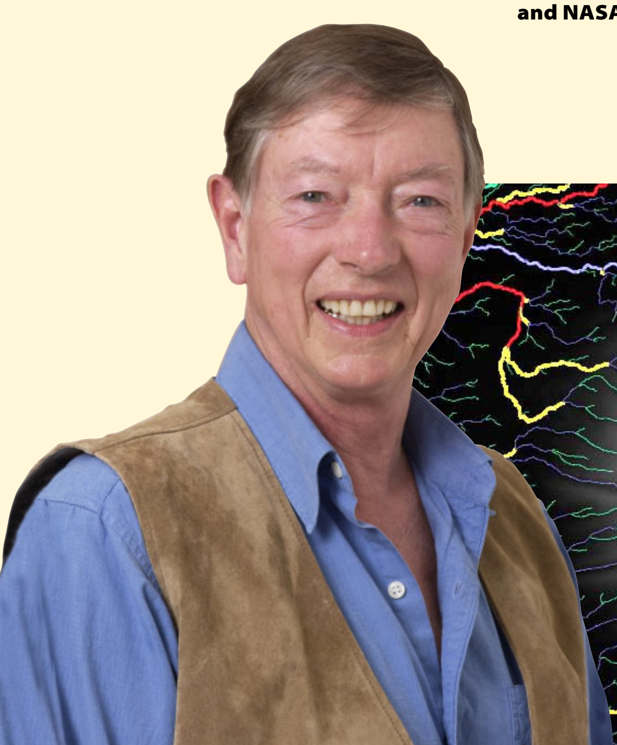
Dr. Thomas Yunck
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: **tpy@jpl.nasa.gov**
Tel: **818-354-3369**

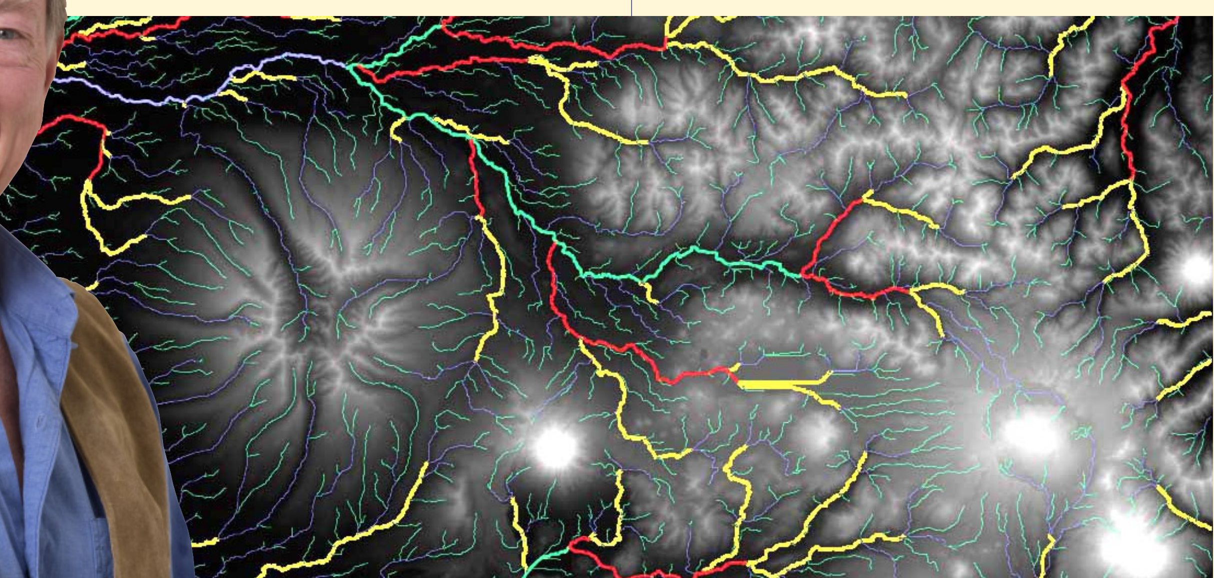
Earth and Space Science Computing with the Information Power Grid

"Grid computing" is simply the logical extension of "distributed computing," but for high-end machines and networks — distributed supercomputing, if you will. More formally, computational grids are persistent networked environments that integrate geographically distributed supercomputers, large databases, and high-end instruments. These resources are managed by diverse organizations in widespread locations, and are shared by researchers from many institutions. Recently the term "global grid" has become popular. Global grid is described as a collection of research and software infrastructure enabling grid computing. The community is self-organized and comes together under the title of Global Grid Forum. Leading practitioners have been the National Partnership for Advanced Computational Infrastructure (NPACI), the National Center for Supercomputing Applications (NCSA), and NASA's Ames Research Center's Information Power Grid (IPG) program.

These grids have become sufficiently mature to be of interest for use in real science, perhaps in ways not possible without the one-sign-up, shared-facility approach that is at the heart of the grid access facilities. For example, we are implementing some aspects of the National Virtual Observatory (NVO) on top of the grid infrastructure. The promise is that by so doing, we can build simple interface mechanisms that allow even the small and thinly connected user to reach all of the nationally (and globally) distributed astronomical data archives, bring them to computational centers for large-scale computing, and return the results to the user. With this vision in place, not only do the data and computational cycles live on the grid, the software lives there as well. When this is reality, the individual researcher needs to have little else than a workstation and a research plan to do big-city science.

Many applications in both Earth and space science fit this general model and it was these





opportunities that led Ames Research Center to enlist JPL in putting together a set of high-impact science studies that could tap the grid's power. To pursue these ideas, Dave Curkendall is leading a new effort to bring three JPL applications to the grid — two in Earth science and one an extension of the NVO work. We are confident that this union of scientists and information technologists will prove a productive one. Indeed, it is opportunities like these that have led to the formation of the Earth System Information Technology Office. This office will seek to bring better focus and coordination to the Section's efforts to bring world-class information technology to world-class science.

Left: A view of the sky near the Galactic Center as seen in the infrared. From a mosaic of 2Mass images constructed by the NVO Montage Project. *Opposite page:* SRTM digital elevation map of Kamchatka in eastern Siberia with derived stream network overlay.

Science Applications

MULTISCALE OCEAN SIMULATION

This will be carried out in collaboration with Dr. Yi Chao, whose objectives are to do regional ocean modeling of the central California coast using a simulation cell size of 5 kilometers. Because the region to be modeled is sensibly influenced by the ocean's dynamics throughout the Pacific basin, a much larger simulation must be executed simultaneously. This can be of lower resolution — 15 kilometers for the whole West Coast area and then the entire Pacific domain at 50 kilometers. Since the IPG can support simultaneous scheduling and execution over multiple machines, we are devising a model where each simulation operates on a separate machine with the periodic exchange of boundary conditions over the networks.

CONTINENTAL STREAM NETWORKS FROM SRTM TOPOGRAPHIC DATA

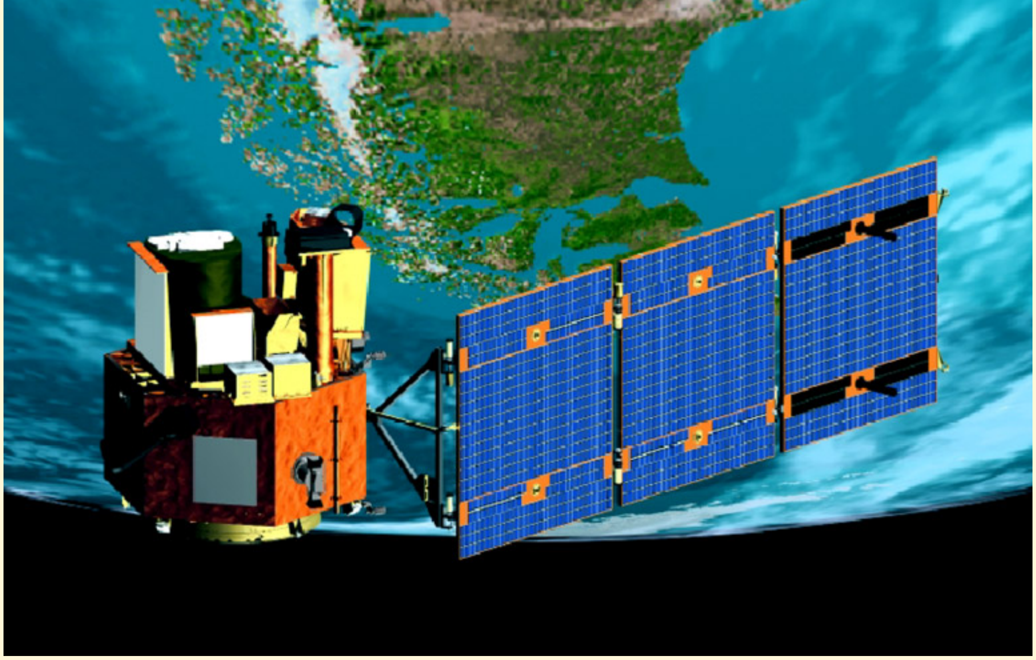
In collaboration with Dr. Eric Fielding and Dr. Ron Blom, we are seeking to exploit the emerging Shuttle Radar Topography Mission (SRTM) data to derive a detailed map of the stream networks, slopes, and drainage area on a continental basis. Stream and drainage networks are used in a variety of fields, but they are a primary data set for surface water hydrology. Hydrologists combine information about rainfall or river flow with the drainage network to determine where and how much water will arrive downstream. This is critical for evaluation of flood hazards and water resources. We seek to derive these networks globally and offer results over the Web as an overlay to the digital elevation model itself.

A BASIC "ALL-SKY" MULTIBAND PLATE SET FOR THE NVO

This effort will be carried out in collaboration with the NASA Earth Science Technology Office Computational Technologies investigation, "High Performance Cornerstone Technologies for the NVO." One of the goals for the NVO is to develop a custom mosaic tool operating on the grid accessed through a Web portal (see *http://yoursky.jpl.nasa.gov* for a prototype of what will be called Montage). To provide a convenient browse tool, we are constructing a medium-resolution sky image (*http:/yoursky.jpl.nasa.gov/dsvo/*). Under the IPG program, we will extend this browse image to the full inherent resolution of the data — 1 arcsecond. The intent is to provide an all-sky set of reference plates of both optical and infrared data, processed with science-grade resampling and background removal algorithms. A Montage user will have a choice — to quickly extract a reference plate, or to tap the full Montage power with appeal to the original data and to the versatile custom mosaic tools.

Contact

Dr. Dave Curkendall
Jet Propulsion Laboratory/MS 126-103
4800 Oak Grove Drive
Pasadena, California 91109-8099
***E-mail:* dwc@jpl.nasa.gov**
***Tel:* 818-354-2406**



In 2003, the New Millennium Earth Observing One (EO1) spacecraft, which is now in its third year of service, will receive new autonomy software designed to increase the science return from the mission [Chien et al., 2003]. The EO1 mission, managed by NASA's Goddard Space Flight Center, has already validated a number of state-of-the-art instruments

Improving Earth Science Return Through Autonomous Scene Selection

for imaging land features from a 705-kilometer Earth orbit. Images are downlinked to Earth at preplanned ground contacts. The instruments can take many more images than can possibly be sent to Earth, so scientists must prioritize the target areas they would like to see. Often, however, clouds can obscure the view of the science targets. As a result, valuable downlink bandwidth is wasted on cloudy images of little use to researchers.

The new autonomy software will analyze the images while still on board the spacecraft. This analysis will determine a number of actions for the spacecraft, such as deleting images with lots of cloud cover or detecting an interesting change in the landscape. Based on this detection, the CASPER (Continuous Activity Scheduling Planning Execution and Replanning) [Chien et al., 2000] onboard mission planning software autonomously changes the command sequence on the spacecraft so that it takes additional images of previously obscured land features or landscape that has undergone a change.

The experiment team is also investigating other onboard science analysis algorithms. These include:

CHANGE DETECTION

Image an area frequently (e.g., once daily) but only downlink when specific science events occur (e.g., fresh impact crater) or downlink summary of change.

FEATURE DETECTION AND TRACKING

Detect and track science features such as volcanoes, lava cones, and sand shapes and downlink images of science items or track dynamic phenomena involving these features (sand shape migration).

NOVELTY DETECTION

Detect science patterns or features that do not regularly occur in the tracked data set and downlink such data for ground-based science investigation.

These algorithms then trigger onboard data processing to, for example, reduce data volume to the minimum required to track the phenomenon of interest, or retarget the spacecraft on subsequent orbits to track the event in further detail. This autonomy may offer a significant increase in mission science return [Davies et al., 2001].

The university-built Three Corner Sat Mission (3CS) [Chien et al., 2001] will also feature onboard data validation, replanning, and robust execution to maximize science return. The 3CS mission consists of three identical spacecraft that are not attitude controlled. The spacecraft will try to take science images of Earth based on models of their tumble. Onboard data validation software will then score each image as to its science value, attempting to pick out images that are mostly of Earth. Onboard replanning software may then target more images based on available power, science image scores, and the next downlink.

References

S. Chien, R. Sherwood, D. Tran, R. Castano, B. Cichy, A. Davies, G. Rabideau, N. Tang, M. Burl, D. Mandl, S. Frye, J. Hengemihle, J. D'Agostino, R. Bote, B. Trout, S. Shulman, S. Ungar, J. Van Gaasbeck, D. Boyer, M. Griffin, H. Burke, R. Greeley, T. Doggett, K. Williams, V. Baker, J. Dohm, "Autonomous Science on the EO-1 Mission," Proceedings of the 7th International Symposium on Artificial Intelligence, Robotics and Automation in Space, Nara, Japan, May 2003.

S. Chien, B. Engelhardt, R. Knight, G. Rabideau, R. Sherwood, E. Hansen, A. Ortiviz, C. Wilklow, and S. Wichman, "Onboard Autonomy on the Three Corner Sat Mission," Proceedings of the 2001 International Symposium on Artificial Intelligence, Robotics, and Automation for Space, Montreal, Canada, June 2001.

S. Chien, R. Knight, A. Stechert, R. Sherwood, and G. Rabideau, "Using Iterative Repair to Improve Responsiveness of Planning and Scheduling," Proceedings of the Fifth International Conference on Artificial Intelligence Planning and Scheduling, Breckenridge, CO, April 2000. (casper.jpl.nasa.gov)

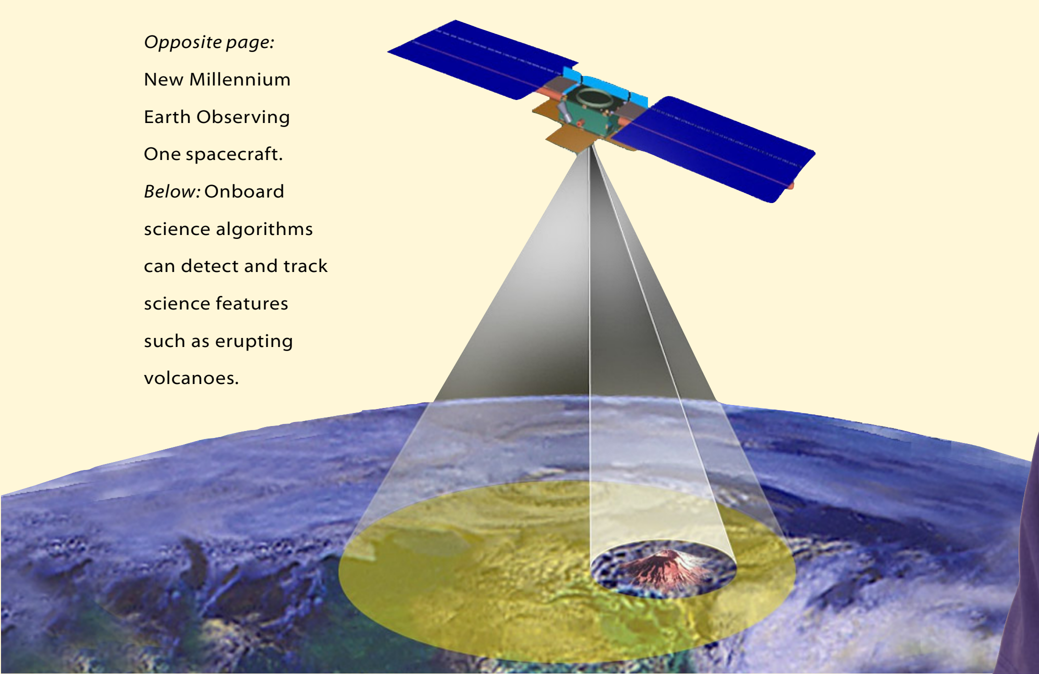
A.G. Davies, R. Greeley, K. Williams, V. Baker, J. Dohm, M. Burl, E. Mjolsness, R. Castano, T. Stough, J. Roden, S. Chien, and R. Sherwood, "ASC Science Report," August 2001. (ase.jpl.nasa.gov)

NASA Goddard Space Flight Center, EO1 mission page: eo1.gsfc.nasa.gov

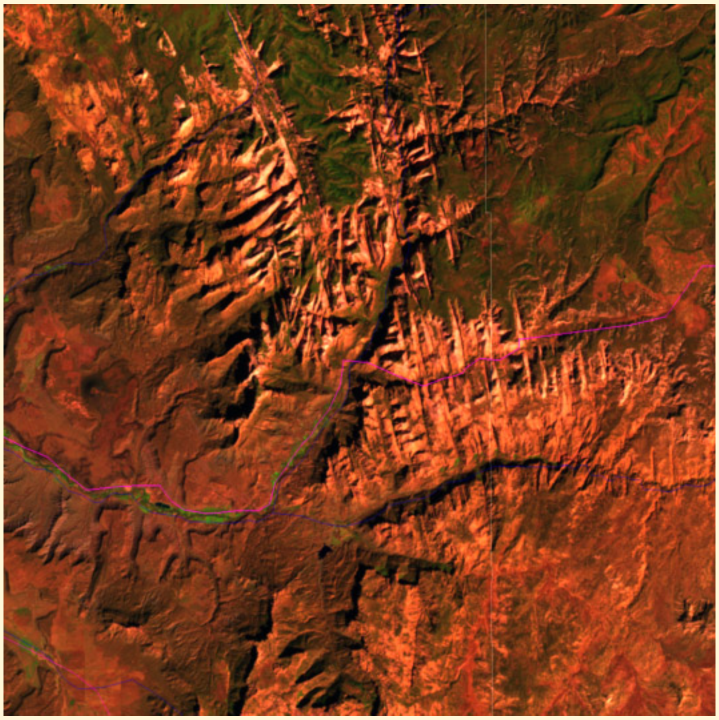
Contact

Dr. Steve Chien
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: **Steve.A.Chien@jpl.nasa.gov**
Tel: **818-393-5320**

Opposite page: New Millennium Earth Observing One spacecraft. *Below:* Onboard science algorithms can detect and track science features such as erupting volcanoes.



A New Dimension in Earth Imaging: MapUS and Beyond



NASA's Earth Science Enterprise seeks to study Earth as an interconnected system of atmosphere, oceans, continents, and life to "understand and protect our home planet." For this purpose, NASA has deployed a network of space and suborbital instrument platforms, which acquire a rapidly increasing volume of data. Supercomputing assets are needed to manage the incoming data stream and rapidly generate and distribute, via the Internet, custom data bundles to a multitude of users.

Above: Spectacular geology of Zion National Park.

Much of the remote-imaging data is so rich in content that it defies any single purpose. It has enormous scientific and economic value; it can help generate unique insights in social and political applications; and it can greatly enhance science education. The challenge is to develop tools to help researchers, scientists, educators, and the interested public access and process these data via Internet links to remote supercomputers.

The Geographical Information Systems (GIS) industry, with NASA as an important contributor, has rallied behind the OpenGIS initiative to stimulate development of interoperable applications to mine the wealth of information from remote sensing. Sharing Earth image products has been one of the first objectives of OpenGIS. This objective was first realized with the introduction of the Web Mapping Server (WMS) specification.

MapUS *(http://mapus.jpl.nasa.gov)*, one of the early WMS servers built by Mr. Plesea in 1999, offers easy access to a 1-arcsecond (30-meter), seamless continental U.S. image mosaic. MapUS hosts an image mosaic built from 429 Landsat 5 images that date from 1992. It makes the mosaic available on the Internet both as a WMS service and as a stand-alone Web site. This mosaic preserves the six high-resolution spectral channels of Landsat 5. Through the Web interface, a user can combine any three channels to generate a color image. Other facilities provided by MapUS include progressive vector map overlay functions, realistic shadows derived from a U.S. elevation model, and orthogonal projection.

MapUS has generated more than a quarter million custom map images in the two years it has been available to the public, with peak access rates in excess of 20 maps per minute. The Web server was built as a prototype for delivering rapid Web access to custom mapping products through efficient use of supercomputing. As witnessed by frequent user comment, this goal has been achieved, with the map generation latency for even the most complex images being below three seconds. Plans are now in place to improve this even further.

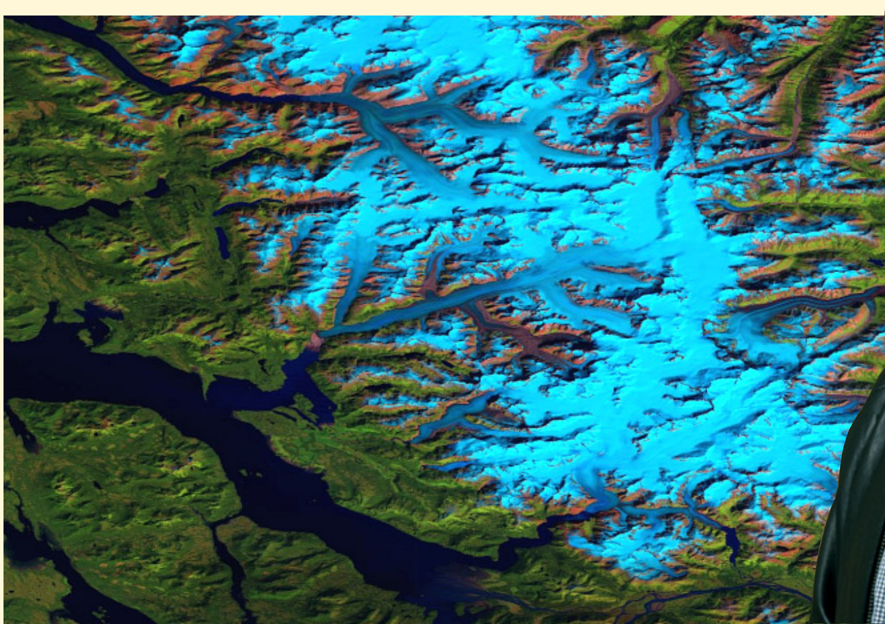
Encouraged by the success of MapUS, an ambitious new project has recently started, with the goal of assembling and providing Web access to a complete Earth landmass map image at 15-meter resolution. The complete Earth image will be nearly 100 times larger than the U.S. image, containing more than 1.5 trillion pixels. The images for this new mosaic, from Landsat 7, will represent a more current crop collected in 1999–2000.

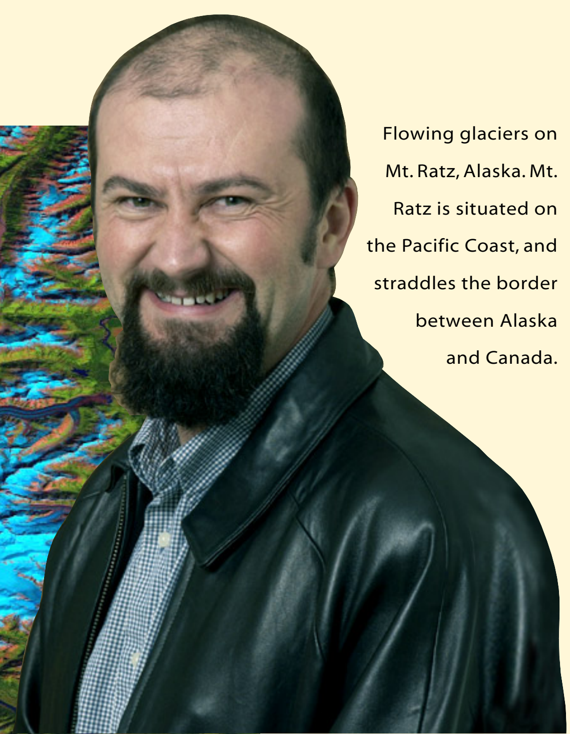
The vastness of this new dataset will stretch current technology limits. It will be possible to build and work with the mosaic only through proper application of supercomputers. In the area of disk storage alone, more than 10 terabytes will be required to hold the original data, intermediate processing steps, and the final mosaic. To cope with this at a reasonable cost we will use a pioneering approach to create a Linux disk farm from inexpensive consumer components. This storage cluster will closely resemble the Linux compute clusters known as Beowulf. The final cost for 10 terabytes of storage, based on 2003 prices, will be below $25,000. The required computation, estimated at 100,000 CPU-hours, will be provided by SGI Origin supercomputers at various locations within the NASA Information Power Grid.

Together with the global elevation model now being created by the joint NASA–National Imagery and Mapping Agency Shuttle Radar Topography Mission (SRTM) project, this mosaic will constitute essential data for the study of Earth systems, and will help to advance science analysis and modeling with real data sources at a resolution and scale not previously achieved.

Contact

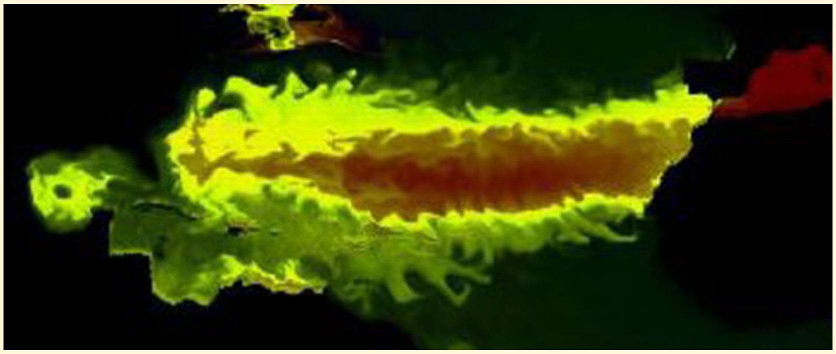
Lucian Plesea
Jet Propulsion Laboratory/MS 126-104
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: **Lucian.Plesea@jpl.nasa.gov**
Tel: **818-354-3928**





Flowing glaciers on Mt. Ratz, Alaska. Mt. Ratz is situated on the Pacific Coast, and straddles the border between Alaska and Canada.

OurOcean: A Web Portal to Serve Near-Real-Time Coastal Ocean Data Products



3-D ocean salinity model data.

The study of coastal ocean problems generally requires higher resolution and higher quality coastal data than the Earth Observing System (EOS) satellites can provide. Since the observations from satellites are either degraded or missing near the coastline, special algorithms are needed to refine the data in coastal regions. In addition, high-resolution, three-dimensional numerical models are crucial for estimating the state of the coastal ocean. For these reasons, a Web portal serving real-time, multidisciplinary coastal ocean data products will benefit many applications, such as weather forecasting, fishing, and long-term studies of the ocean/climate relationship.

In collaboration with JPL oceanographer Dr. Yi Chao, Dr. Peggy Li and Dr. Joseph Jacob have developed a Web portal prototype called OurOcean *(http://ourocean.jpl.nasa.gov)*. OurOcean is an end-to-end system for data retrieval, data archiving, data processing, and data distribution, with a focus on the East Pacific Ocean. The purpose of this portal is to afford users easy access to ocean science data, run data assimilation models and visualize both data and models. Through OurOcean, users with minimal resources can access large datasets and interact with sophisticated ocean models.

Currently, OurOcean provides both real-time and retrospective analysis of remote sensing data and ocean model simulations in the Pacific Ocean, with a focus on the coastal ocean from Baja California to the Gulf of Alaska.

OurOcean serves the following datasets:

- Daily ocean surface wind datasets collected by the QuikScat scatterometer and stored at JPL's Physical Oceanographic DAAC Center.
- Twice-daily ocean surface wind from the Coupled Ocean Atmosphere Mesoscale Predication System (COAMPS) model stored at the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center (FNMAC).
- A blended wind product produced at JPL.

- A three-dimensional ocean temperature, salinity, and current velocity dataset generated by the Regional Ocean Model System (ROMS).

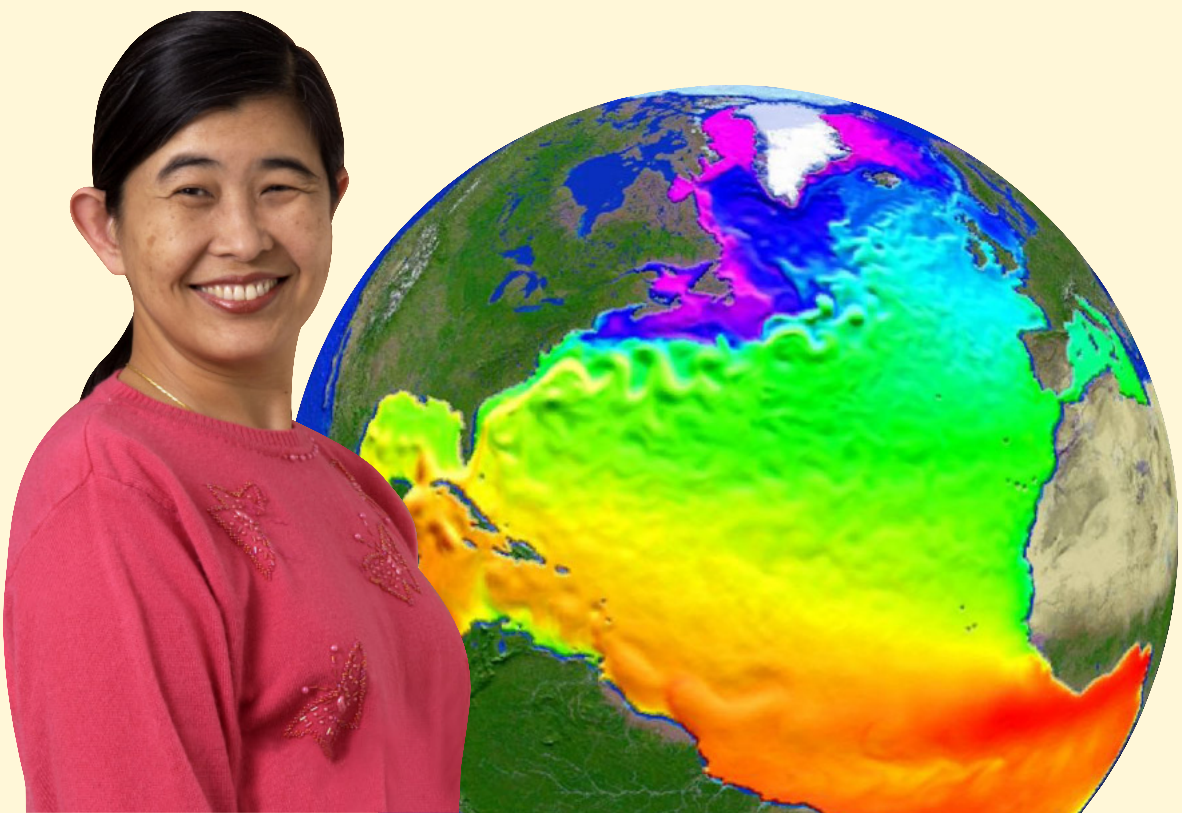
The Live Access Server (LAS) is used to serve data over the Web, and the Ferret Data Visualization and Analysis System is used to render visual products requested by the user. OurOcean users work with an interactive Web interface that allows them to select a subset of a larger dataset by clicking and dragging on a zoomable map. They can choose from a variety of outputs, such as a GIF or PostScript image, a raw data file, or a NetCDF file. A user can also compare the difference between any two variables.

The OurOcean server downloads the QuikScat and COAMP datasets daily from their distributed archives, re-grids and re-formats them, runs a blending program to generate the blended wind dataset and puts all three datasets on the Web. The blended wind data feed into a three-dimensional model running on a remote supercomputer that generates real-time, three-dimensional ocean datasets, available from OurOcean. OurOcean provides a unified interface to diverse users for accessing multidisciplinary ocean datasets focusing on a specific region of interest.

In the future, OurOcean may be expanded to serve on-demand modeling datasets. A user will be able to select a region of interest, data resolution, simulation duration, and boundary conditions of the model via the Web interface and submit a request to the Web server. The server will then configure the model, schedule remote supercomputing resources to run the model, manage the data assimilation and data transfer, monitor the model execution, and deliver the output to the OurOcean Web server for the user to retrieve. Eventually, OurOcean will serve as a "one-stop shop" for very large distributed datasets and easy interaction with complex three-dimensional models.

Contact

Dr. Peggy Li
Jet Propulsion Laboratory/MS 126-104
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: P.P.Li@jpl.nasa.gov
Tel: 818-354-1341



Ocean surface temperature model data.

Scientists Finding the Right Data: Data Mining of Massive Time-Series and Image Datasets

Many of today's Earth science spacecraft generate such high volumes of data that scientists cannot complete a traditional, in-depth, manual analysis of an entire dataset. Investigators must make hard decisions about how to maximize the science return for the time they can allot to analysis. Recent advances in autonomous data-mining are providing valuable tools to assist scientists facing this challenge.

For example, an analyst can now perform a rigorous examination on a smaller, representative sample of the full dataset, then feed the results to a trainable data-mining algorithm. The algorithm learns what is important to the scientist and proceeds to search the complete dataset to extract key areas of interest for further study.

Dr. Dennis DeCoste is working on a number of data-mining projects with applications to a wide variety of cross-enterprise NASA missions, including engineering and science data analysis tasks for the Space Shuttle, Mars rovers, and Terra/MISR. One of these efforts is focused on learning accurate, yet efficient, classification models from massive Earth science Multi-angle Imaging SpectroRadiometer (MISR) image datasets. To demonstrate the effectiveness of the method, clouds were selected as the first type of target to study. Clouds are fundamental to global climate studies being done by the MISR science team and other Earth scientists. The MISR instrument provides unique sensing capabilities that may offer far better global cloud identification than ever before. However, MISR's unique multi-angle viewing requires new types of cloud identification algorithms. It is crucial to validate and refine these algorithms globally, across all types of regions. The enormous volumes of raw MISR data do not come with "ground truth" labels of where each type of cloud occurs. Scientists must laboriously review the data and decide over which regions to run additional tests, what the results should be, and what adjustments to existing algorithms might reduce misidentifications. Our machine learning methods automate this iterative process, making it more systematic and minimizing "in-the-loop" scientist effort.

Below: Computer-generated image showing the Terra spacecraft, with the MISR instrument on board, orbiting Earth.

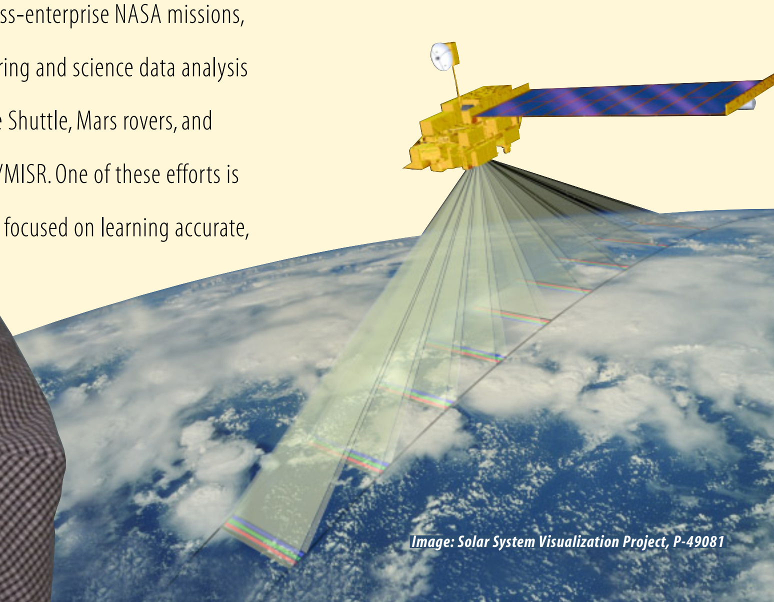
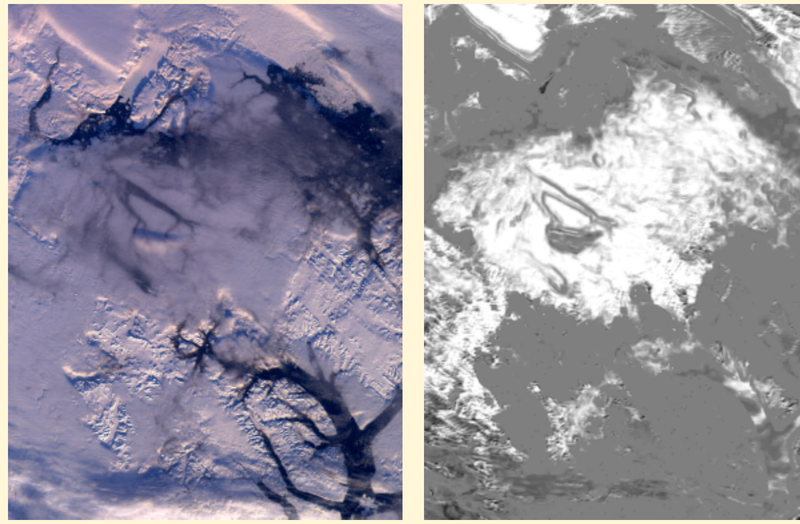


Image: Solar System Visualization Project, P-49081



MISR arctic cloud detection: MISR image data *(left)* vs. output of trained statistical model *(right)* where white indicates cloud detection.

The accompanying figure illustrates a small sample of MISR image data, along with the output of the trained statistical model. The active learning algorithm iteratively interacts with the scientist, requesting labels for pixels for which labels would be most helpful. In this way, scientists can have maximum impact on improving the trained classifier models, with minimal manual effort. Traditional approaches to acquiring labels from scientists are often wasteful because most of the labels offered by the scientist are not informative — the current classifier model will already find most of them easy to label correctly. Our approach focuses the scientist's attention on the data for which the current model is most uncertain. Doing this well also requires learning models for what sort of data scientists cannot confidently label. Otherwise, the approach would quickly focus attention on the data that are inherently noisy (e.g., fuzzy image quality) and can be classified well neither by computers nor scientists — quickly degrading to repeated "pestering" of scientists to perform the same impossible tasks. Overcoming this challenge is a key focus of our ongoing work, a collaboration between Dr. DeCoste, computer scientist Dominic Mazzoni, and the JPL MISR Science Team, including Dr. Amy Braverman, Dr. Roger Davies, and Dr. David Diner.

Other data-mining and time series analysis projects led by Dr. DeCoste include Toogle and Simmarizer.

TOOGLE is a Web-based search engine for time-series data that enables engineers and scientists to query large data sets to find historic behaviors similar to a current one of interest. For example, querying with a newly observed anomaly signature (over specific sensors and a specific time period) allows the discovery of similar historic behaviors for further analyst evaluation. Work-arounds previously derived for that behavior could expedite understanding and handling of the current problem.

SIMMARIZER discovers summary knowledge implicit in simulators. We have initially focused on the automated discovery of initial conditions that lead to certain science events of interest, such as a configuration of satellites (moons). For this example, we run expensive asteroid-impact simulators from many different initial states, along with statistical learning models, such as neural networks and support vector machines. The trained models can then be used to predict whether any new initial state (specific impactor velocity, angle, and impactor/planet mass ratio) would lead to the science event of interest. This predictive capability reduces by orders of magnitude the number of expensive simulations that are unsuccessful. The models take mere seconds to winnow the list of possible initial state candidates so that the simulations, which can take up to a week to run on one Beowulf computer node, are saved for the most promising candidates. This work is done in collaboration with Dr. William Merline and other colleagues at the Southwest Research Institute.

Selected Publications

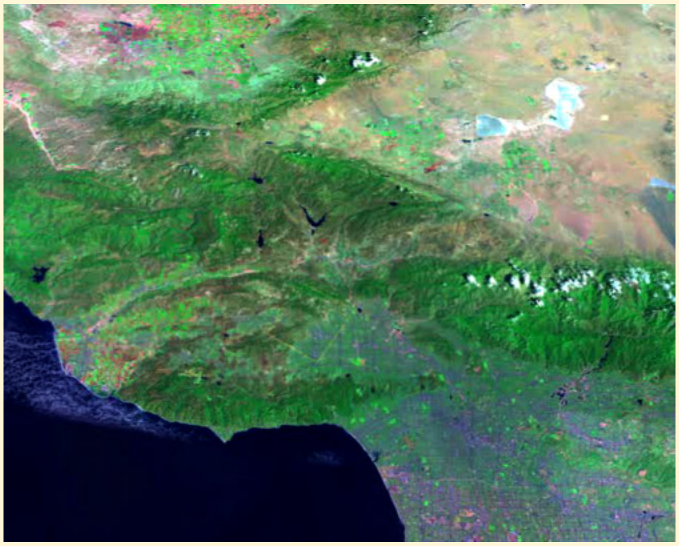
D. DeCoste, "Anytime Interval-Valued Outputs for Kernel Machines: Fast Support Vector Machine Classification via Distance Geometry," Proceedings of the International Conference on Machine Learning (ICML-02), July 2002.

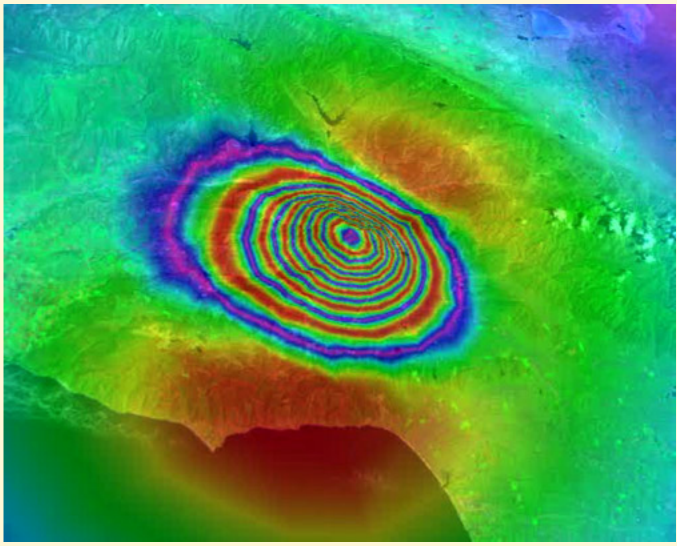
D. DeCoste and B. Schoelkopf, "Training Invariant Support Vector Machines," Machine Learning Journal, Volume 46(1–3), 2002.

E. Mjolsness and D. DeCoste, "Machine Learning for Science: State of the Art and Future Prospects," Science, Volume 293, pp. 2051–2055, September 14, 2001.

Contact

Dr. Dennis DeCoste
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: **Dennis.M.Decoste@jpl.nasa.gov**
Tel: **818-393-5366**





GeoFEST: A Tool for Modeling Earthquakes

Dr. Greg Lyzenga conducts research in earthquake mechanics and modeling to probe the physical processes and interactions that govern the buildup and release of stress in the Earth's crust and interior. Analytic and numerical simulation methods are used to examine candidate models of the deformation processes occurring at tectonic plate boundaries. Studies of this kind are critical to understanding how, why, and when earthquakes occur. The long-dreamed-of goal of earthquake prediction will not be possible until geophysicists can come to grips with the sheer complexity of stresses and material properties, which vary spatially and temporally throughout Earth's interior.

Geophysical parameters, such as depths and extents of earthquake faulting or elastic/viscoelastic rock properties, may be inferred in special cases where directly relevant observational constraints are available. For example, if we have high-precision GPS geodesy or synthetic aperture radar interferometry (INSAR) data, we can perform inversion studies to deduce the geophysical parameters outlined above. It is far more common, however, for earthquakes to occur with little or no observational constraints. In these cases, competing hypothetical tectonic scenarios are investigated using a technique of exploratory forward models.

A critical utility for exploratory forward modeling is the Geophysical Finite Element Simulation Tool (GeoFEST). GeoFest is a versatile modeling tool designed to simulate arbitrarily complex geometrical arrangements of faults, material properties, and driving forces subjected to quasi-static deformation. The GeoFEST finite-element code had its origins in the 1980s as a two-dimensional strain-

Far left: Satellite imagery showing the epicentral region of the January 1994 Northridge earthquake. The San Fernando Valley occupies the center of the image, with the Antelope Valley and Mojave desert at the top, and the Malibu Pacific coast at the bottom. The San Andreas and Garlock faults form the prominent V-shaped feature in the upper half of the image. *Near right:* Synthetic contours of uplift displacement caused by the coseismic effects of the Northridge earthquake, superimposed on the mapping imagery of the satellite image. The three-dimensional time dependent model was generated by GeoFEST, working on a computational grid of 55,369 viscoelastic tetrahedral elements. Maximum uplift in the epicentral region is approximately 40 cm. These data comprise a single frame of movie simulation describing the time-dependent adjustment of stress and strain over several years following the earthquake.

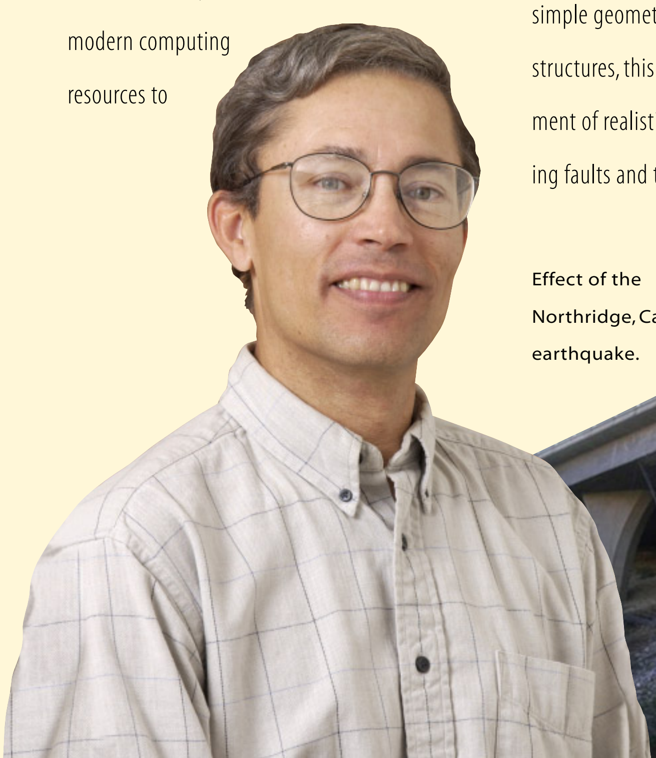
simulation code to study viscoelasticity in simple cross-section or map view geometries. During this period it was also used as a testbed for the development of parallel computing strategies in large-scale finite-element applications, where it found one of its earliest realizations on the Hypercube family of parallel processors developed at Caltech and JPL.

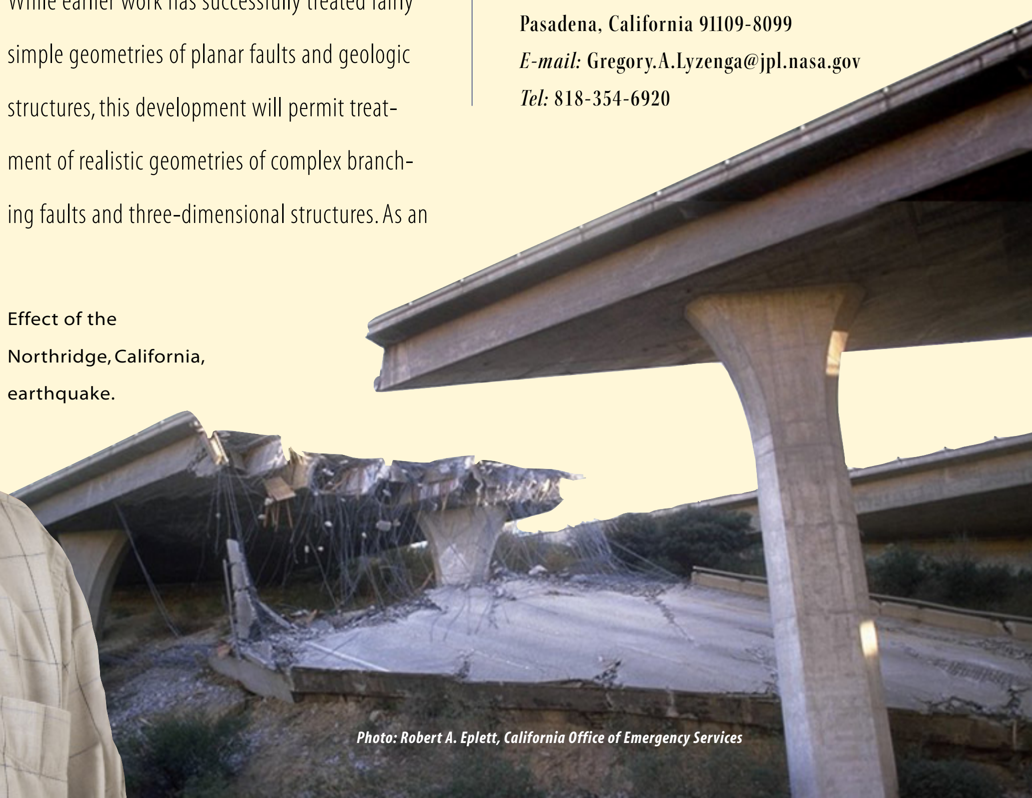
Continued development led to the current version of GeoFEST, which makes effective use of modern computing resources to fully solve three-dimensional finite-element domains. Research and development with GeoFEST continues vigorously, focusing on both the development of system enhancements and the scientific application of existing capabilities. Among the most important and eagerly anticipated new GeoFEST developments is the integration of parallel solution techniques with largely automated parallel domain gridding and visualization tools. While earlier work has successfully treated fairly simple geometries of planar faults and geologic structures, this development will permit treatment of realistic geometries of complex branching faults and three-dimensional structures. As an early validation test, we recently computed and visualized a three-dimensional deformation model for the 1994 Northridge earthquake.

Other new capabilities under development or planned for the near future include models incorporating rate- and state-dependent fault friction constitutive laws and isostatic buoyancy forces. These enhancements will increase the fidelity with which time-dependent tectonic processes can be simulated. Working in concert with the other tools and investigators in General Earthquake Models (GEM) (*http://www-aig.jpl.nasa.gov/public/dus/gem/*), the code is providing a numerical laboratory for the study of physical interactions governing the earthquake process on time scales of years to millennia.

Contact

Dr. Greg Lyzenga
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: Gregory.A.Lyzenga@jpl.nasa.gov
Tel: 818-354-6920





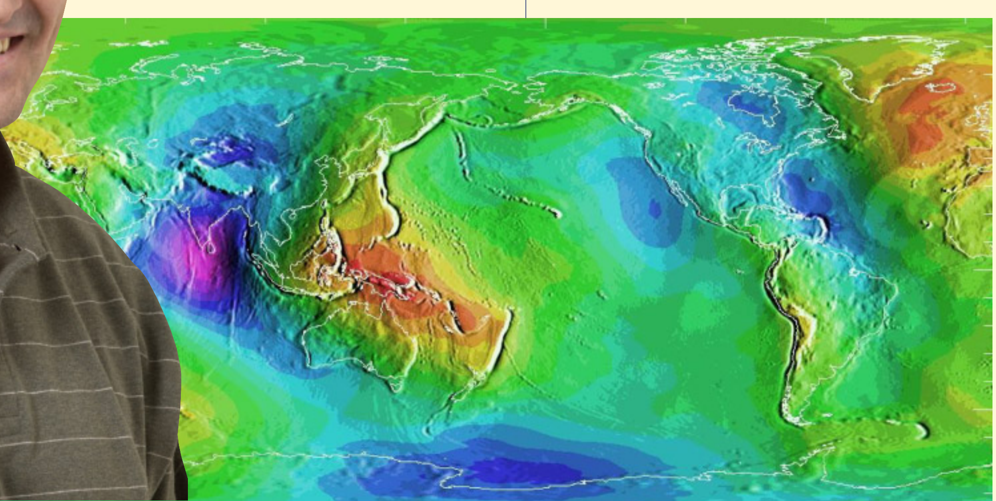
Effect of the Northridge, California, earthquake.

Photo: Robert A. Eplett, California Office of Emergency Services

Quantum Sensors: Enabling a New Sensitivity for Earth Science

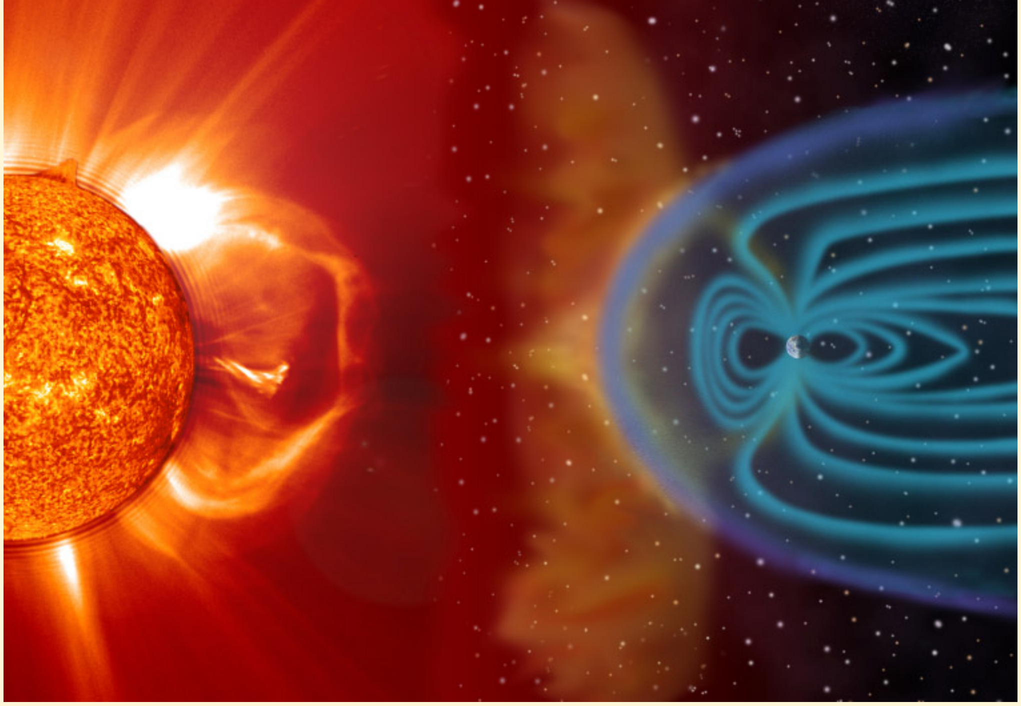
Technological advances in quantum optics and atomic physics during the last decade have provided us with tools for the development of a new generation of highly accurate quantum sensors. Some of these can be applied in new Earth science instruments such as gravimeters, gravity gradiometers, and magnetometers.

Quantum gravimeters and gravity gradiometers may one day greatly enhance our global models of the Earth's gravity field.



New technologies allow us to cool atomic ensembles to temperatures close to absolute zero, where the atoms have the lowest amount of energy and travel with velocities on the order of only several millimeters per second. At these temperatures, the atomic ensemble enters a condensed phase and forms a Bose-Einstein condensate (BEC).

The cold atoms can be controlled and directed by optical pulses. Thus, we can collect atoms in small spatial regions, split the atomic clouds, and both create atomic beams and manipulate those beams. We can also build an atom laser and use the unique properties of matter-waves for the development of highly accurate quantum sensors. The matter-wave properties of atomic beams are used in atom gyroscopes, atom gravimeters, and gravity gradiometers. Such instruments exploit the sensitivities of atom interferometers to detect phase shifts caused by rotations or atom–gravity interactions. An atom gyroscope operating with beams of cold atoms is an exceedingly sensitive rotation sensor. Owing to the great difference in masses of atoms and light quanta, $m_A/m_{ph}=10^{10}$, an atom gyroscope greatly exceeds the sensitivity of the best laser gyro.



Ultrasensitive magnetometers can help scientists better measure and understand the Earth's magnetosphere.

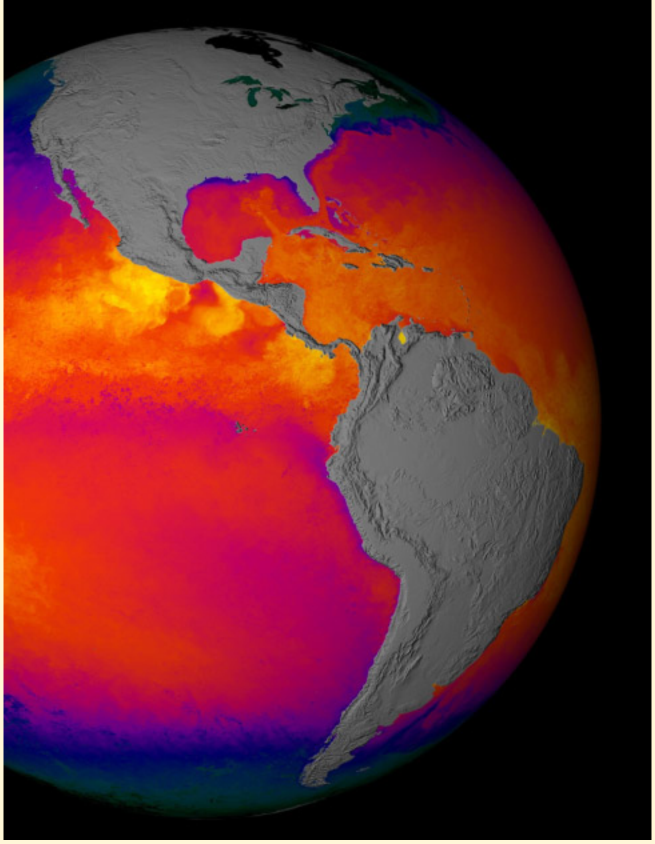
Moreover, the use of correlated beams of alkali atoms can further improve the sensitivity. As a result, the BEC atom gyroscope can exceed the sensitivity of current gyros by several orders of magnitude. These new sensitivities can be exploited as a solution for NASA's new requirements for ultraprecise spacecraft stabilization and structural control.

In an effort to develop more efficient technologies for the measurement of the gravitational field, sensitive gravimeters and gravity gradiometers have been designed and are continuously being improved. Theoretical and experimental studies have demonstrated that atom interferometers can boost the accuracy of gravitational field measurements. In laboratory experiments, the atomic gravimeters can measure the gravitational field with a sensitivity of $\sim 10^{-11}$ g and the gravity gradient with the sensitivity of $\sim 10^{-2}$ Eotvos. The sensitivity of atom gravimeters in space experiments can be two orders of magnitude higher. One of the advantages of atom interferometric gravimeters and gravity gradiometers is that they operate with optically cooled atoms and do not require cryogenic elements that are used, for example, in superconducting quantum interference device (SQUID) gravimeters and gradiometers. The use of highly sensitive gravimeters and gravity gradiometers can provide tremendous future benefits to NASA programs for the study of Earth and other planets.

Magnetic-field detection is an important component of NASA's advanced scientific research. The detection of subtle magnetic-field variations from satellite platforms requires ultrasensitive magnetometers. Different types of magnetometers operating on moving platforms, such as SQUID magnetometers and optical pumping magnetometers, are currently used in a number of geophysical and space science applications. Another type of the recently proposed optical magnetometer utilizes an electromagnetically induced transparency (EIT) in a media of alkali atoms. The EIT magnetometer uses the dispersion properties accumulated in the phase shift of the optical interferometer when one of the beams passes through an alkali medium. The sensitivity of a magnetometer can be improved by using a condensed alkali medium and by boosting the optical interferometer sensitivity. In the last several years, there has been an explosion of research in the use of quantum-entangled photonic systems for advanced technologies. Quantum photon entanglement can provide an additional improvement in interferometer sensitivity. The use of entangled photons in the optical beams will allow us to reach the noise phase limit of df~1/N for an optical interferometer, and to build the magnetometer with a sensitivity of $\sim 10^{-14}$ Gauss, or two orders of magnitude higher than that of the best current magnetometers.

Contact

Dr. Igor Kulikov
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: Kulikov@jpl.nasa.gov
Tel: 818-393-5369



Deriving geophysical quantities of interest, such as temperatures, gravity anomalies, and surface heights from raw sensor data can require sophisticated "inversion" processes involving the observational data along with descriptive mathematical models. Inversion results from several NASA instruments are shown here. New techniques devised by Dr. Zak may help to improve certain kinds of difficult inversions.

Inverse Problem Approach to Information Processing

Inverse problems arise when a mathematical model of a physical phenomenon must be reconstructed from available sensor data. The reconstructed model describes a whole class of similar phenomena in a parametric form; one can then analyze unobserved phenomena of the same class by varying the corresponding parameters. Observed changes in retrieved model parameters can be interpreted as anomalies, novelties, and the like. By running the retrieved model forward, one can attempt to predict expected values of the phenomenon under observation and perhaps identify potential hazards in time to issue alerts and take precautions.

Inverse problems are encountered in every domain of Earth science (see, for example, pp. 18–19 of this report). Unlike direct problems (given a model, find the solution), inverse problems usually do not have unique solutions. To deal with this, information in addition to the sensor data is needed. Dr. Zak has developed a new methodology (the Gray-Box approach) in which this additional information is extracted from First Principles — for example, from conservation of mass, energy, or momentum. His methodology is applicable to sensor data given as time series or as a spatial distribution.

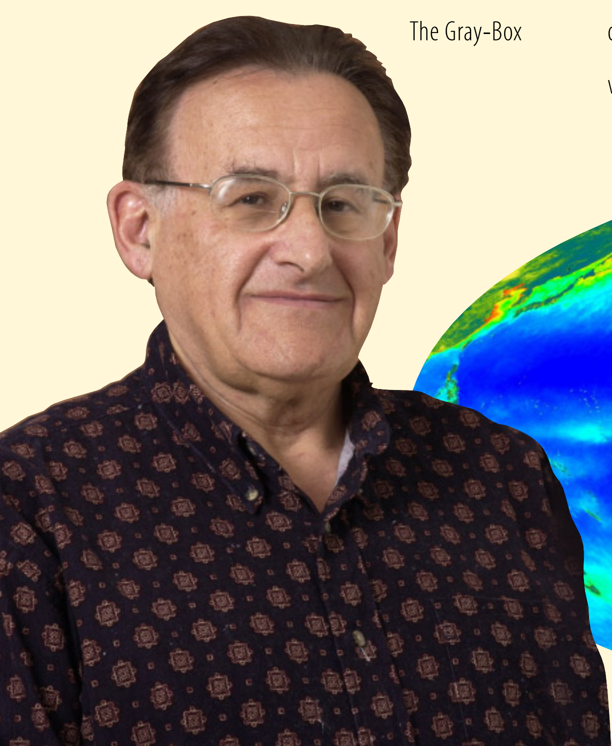
The time series (for example, weather or earthquake patterns) are subjected to a dynamical filtering as result of which the components satisfying the First Principles are eliminated. In the case of weather, these Principles can be reduced to the Reynolds equations augmented by a theoretical closure proposed by Dr. Zak. In the case of earthquakes, equations of elasto-plastic continuum can be applied. The filtered series are treated as samples of an underlying stochastic process. This process is decomposed into stationary and nonstationary (trend, oscillations) components. The nonlinearities are handled by feed-forward neural networks. As a result, a reconstructed model is represented in a parametric form suitable for analysis of anomalies or for making predictions.

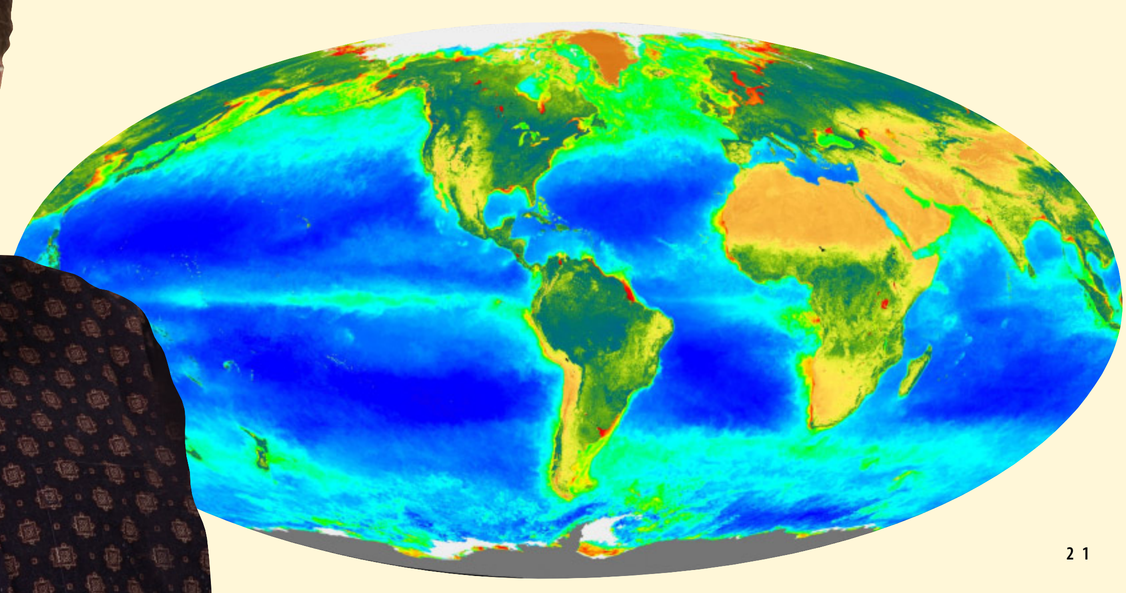
The Gray-Box philosophy can also be applied to spatially distributed data. These data, which may represent an anomaly in a gravitational or magnetic field, are compared with a corresponding theoretical field derived from a model anomaly expressed in a parametric form. By applying the best fit algorithm, the location and shape of the anomaly can be obtained. The Gray-Box approach can be adapted to processing images. For instance, a moving contour of a Jupiter cloud can be represented as a system of moving and interacting vortices that satisfy the Helmholtz equation under the condition that the streamline enveloping the system coincides with the observed contour.

A variant of this methodology is based upon a new dynamical filter developed by Dr. Zak. He recently discovered a new phenomenon — soliton resonance — which emerges in nonlinear dispersive dynamical systems. The phenomenon is based upon the interaction between an externally induced soliton and "eigen-solitons" of the corresponding homogeneous equation. It turns out that the soliton-shaped external energy pumped into the dynamical system induces and intensifies eigen-solitons in the same way classical resonance operates. Because a soliton describes a solitary wave moving with a constant (or slowly changing) speed, the dynamical system will amplify such a motion while suppressing all irregular motions. A useful application of this filter is the detection of faint asteroid trajectories embedded within a sequence of noisy images. The algorithm starts by converting values from the sensor into values for the corresponding potential. This potential is presumed to mimic the shape of the original sensor data, which may, for example, represent the brightness of pixels in a sequence of images. Formulated as a function of time and space, the potential is then transformed by a filter having particular nonlinear dispersive properties suited to the phenomenon of interest, such as asteroid motion. At the filter output, only those components having the form of the moving source will survive, thus allowing the asteroid trajectory to be revealed within a noisy background.

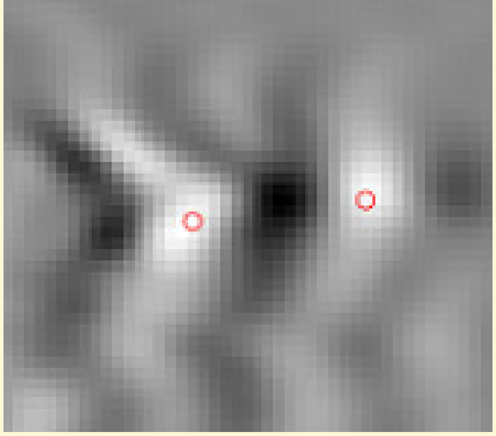
Contact

Dr. Michail Zak
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: Michail.Zak@jpl.nasa.gov
Tel: 818-393-5351





Applying Advanced Image Processing Techniques to Enhance Underground Radar Images



Ground Penetrating imaging Radar (GPiR) combines efficient radar surveying with precise positioning control and advanced signal processing, allowing the creation of high-resolution 3-D radar images of the subsurface. These 3-D images can be analyzed to detect and identify subsurface features, such as underground pipes, utility lines, etc. Currently, much of the analysis is conducted manually by an expert operator who must visually identify and track each feature. For more efficient and accurate analysis, there is a need for algorithms that can automatically identify and track subsurface features with minimal human supervision.

Above: The filtered image shows two prominent peaks near the center. The red circles indicate that two underground pipes have been detected.

JPL, in collaboration with Witten Technologies Inc. of Boston, is applying its expertise to enhance underground radar images made for Consolidated Edison Company of New York, Inc. The team is examining images of lower Manhattan collected in August 2001 and January 2002 to detect underground pipes and utility lines. In addition, Witten is providing JPL with data from around the World Trade Center area before and after the September 11, 2001, attack. Processing of these images will help provide a clearer picture of what's beneath the surface. Comparing before and after radar images of the same area may enable the team to detect underground changes and assess the extent of damage.

JPL has created a suite of algorithms based on machine learning and pattern recognition techniques that allows automatic mapping of the underground pipes and other utilities by using sets of 3-D images from the Witten GPiR system. The suite includes image processing, pattern/feature recognition, and feature/object linking algorithms that can automatically identify and track subsurface features. The preliminary results are very promising. The algorithms can detect and identify subsurface pipes via template pattern matching with high success and low false-positive rates. JPL is now developing feature/object linking algorithms that will automatically generate a map of connected subsurface objects. The new algorithms will also be used in the analysis of before and after radar images from the site of the World Trade Center.

Graphic showing underground imaging.

Image courtesy of Witten Technologies.

Contact

Dr. Amir Fijany
Jet Propulsion Laboratory/MS 126-347
4800 Oak Grove Drive
Pasadena, California 91109-8099
E-mail: Amir.Fijany@jpl.nasa.gov
Tel: 818-393-5342

Award-Winning Technologists 2002

Dr. Jonathan Dowling

WILLIS E. LAMB MEDAL FOR ACHIEVEMENT IN QUANTUM OPTICS AND LASER SCIENCES

The particular citation is for Dr. Dowling's work in "quantum enhancement of spatial resolution" (quantum lithography). The Willis E. Lamb Medal, named after the 1955 Nobel Laureate and quantum physics pioneer, is one of the most prestigious awards in the field of quantum optics and laser science. Past winners include Ali Javan, for the invention of the helium–neon laser; Melvin Lax, for his fundamental work on the quantum theory of the laser; Fredrico Capasso, for his work on the quantum cascade laser; and Herbert Walther, of the Max Planck Institute in Quantum Optics in Germany, for his work on single-atom masers.

Dr. Anna Tavormina

JPL RECIPIENT OF THE WOMEN AT WORK MEDAL OF EXCELLENCE

Women at Work is a nonprofit organization based in Pasadena that serves the greater Los Angeles community. The primary focus of this organization is to provide a resource for women to learn about new or alternate career opportunities, and to help women advance their careers. Each year, the Women at Work organization holds an award banquet where a woman from each contributing company is honored with a Medal of Excellence. The JPL Director's Advisory Council for Women (ACW) coordinates the nomination and the final selection of the winner from JPL. Of the 16 women nominated for this award, Dr. Tavormina's nomination was endorsed unanimously by the selection committee.

Dr. Christoph Adami

NASA EXCEPTIONAL ACHIEVEMENT MEDAL

Dr. Adami received this honor for his research in extending the concept of fitness in the theory of evolution to high mutation rates ("survival of the flattest"), and demonstrating its universality with experiments on digital, rather than terrestrial, organisms. This medal is a prestigious NASA award that is presented to a number of carefully selected individuals and teams who have distinguished themselves by making outstanding contributions to the NASA mission.

Dr. Dmitry Strekalov

LEW ALLEN AWARD FOR EXCELLENCE

This award recognizes and encourages significant individual accomplishments or leadership in scientific research or technological innovation by JPL employees during the early years of their professional careers. Dr. Strekalov has established a significant new area of research at JPL: experimental quantum imaging and metrology. He built the new JPL quantum Internet testbed from the ground up. Bringing the new testbed on line is an important milestone in development of the quantum computing initiative at JPL, which has been of interest to both NASA and the Department of Defense. Through his initiative, the testbed is now of world-class capability and will have a significant impact on experimental efforts in researching quantum technologies theory (one of JPL's current strategic thrusts for technology development).

Award-Winning Technologists 2002

Dr. Wolfgang Fink

NASA SPACE FLIGHT AWARENESS AWARD

Dr. Fink developed and designed the three-dimensional, computer-automated threshold Amsler Grid test, which is capable of detecting even subtle visual field defects, undetectable by state-of-the-art standard automated perimetry. In collaboration with the Doheny Eye Institute at USC, over 200 patients have been successfully examined or screened for glaucoma, age-related macular degeneration, optic neuritis, anterior ischemic optic neuropathy (AION), and certain brain tumors.

Space Flight Awareness honorees, left to right (front row): Katherine Levister, Chau Buu; (back row): Jan Martin, Eric Gurrola, Astronaut Mark Kelly, Jerry Clark, Wolfgang Fink, and Son Ho. The honorees received a VIP tour of NASA Kennedy Space Center as part of the award.

2002 NASA Space Act Award Recipients

DR. DENNIS DECOSTE

BEACON monitor technology tone-detection software

DR. DEBORAH JACKSON

High security optical encryption for multimedia electronic image transmission

DR. AMIR FIJANY

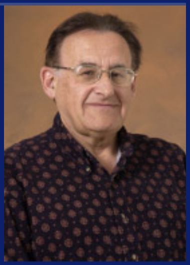
Massively parallel algorithms for signal-processing applications using charge domain computing devices

DR. COLIN WILLIAMS *(left)* **and DR. JONATHAN DOWLING**

Quantum interferometric lithography: exploiting nonlocal quantum entanglement to beat the diffraction limit

DR. AMIR FIJANY *(above)* **and DR. MICHAIL ZAK** *(right)*

High-precision computing with charge domain devices



The Jet Propulsion Laboratory (JPL) just entered its fifth exciting decade of space exploration. JPL is located on 177 acres in Pasadena, California, and employs over 5,000 people. It is managed by the California Institute of Technology for the National Aeronautics and Space Administration (NASA) as a federally funded research and development center. The collegial atmosphere of the Laboratory and the unique mission of JPL and NASA attract the best and brightest from across the United States and from foreign institutions.

Our success is made possible by investments in critical technologies and research, a creative workforce, and collaborations with other NASA centers, government agencies, and university and industry partners.

For more information on how to take advantage of the opportunities that JPL can offer your organization, please contact the National Space Technology Applications Office at 818-354-3829.

THE NASA MISSION

To understand and protect our home planet

To explore the Universe and search for life

To inspire the next generation of explorers

...as only NASA can.

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 400-1080 04/03